Tropical Moored Buoy Array Program

Michael J. McPhaden[1], Christian Meinig[1], and Rick Lumpkin[2]
[1] Pacific Marine Environmental Laboratory Seattle WA
[2] Atlantic Meteorological and Atmospheric Laboratory, Miami FL

1. Project Summary:

This report describes FY 2006 progress in the implementation of the Tropical Moored Buoy Array program as a NOAA contribution to development of the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the Global Earth Observing System of Systems (GEOSS). The goal of the moored buoy program is to provide high quality moored time series and related data throughout the global tropics for improved description, understanding and prediction of seasonal to decadal time scale climate variability. Focus on the tropics is dictated by its role as a heat engine for the Earth's climate system, engendering phenomena such as the El Niño/Southern Oscillation (ENSO), the monsoons, the Indian Ocean Dipole, and tropical Atlantic climate variability. This program supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also provides key observational underpinning for the international Climate Variability and Predictability (CLIVAR) program's research efforts on climate variability and change. Management of the tropical moored buoy array program is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on the program can be found at http://www.pmel.noaa.gov/

Five major elements to the Tropical Moored Buoy Array program are described below. These are the Pilot Research Moored Array in the Tropical Atlantic (PIRATA), the Indian Ocean array, Flux Reference Stations, Tropical Salinity, and Engineering Development. Discussion of these elements is followed by comments about fishing vandalism, a summary of community service, and a list of FY 2006 publications.

2. Accomplishments

2.1 PIRATA

PIRATA is a joint effort between the U.S. (NOAA/PMEL and NOAA/AOML), France (Institut de Recherche Scientifique pour le Développement en Coopération [IRD] and Meteo-France), and Brazil (Instituto Nacional de Pesquisas Espaciais [INPE] which is the Brazilian space agency and Diretoria de Hidrografia e Navegacao [DHN] which is the naval hydrographic service). The program targets Atlantic climate variability and tropical storm formation in the maximum development region for hurricanes. PMEL is charged with providing equipment, technical support for moorings and instrumentation, and support for data processing, dissemination, and display. AOML provides for collection of some key ship-based measurements in support of the mooring program. France and Brazil provide ship time and support for equipment shipments as part of a trilateral agreement to maintain the array. France and Brazil also provide technician support at sea. NOAA provided PIRATA ship time for the first time in FY 2006.

The 10-mooring PIRATA core array configuration (as agreed upon for the 2001-2006 consolidation phase of the program, plus three ‘Southwest (SW) Extension” moorings sponsored by INPE in Brazil (first deployed in August 2005), were continued in FY 2006. A “Southeast (SE) Extension” mooring sponsored by the University of Capetown, South Africa, was deployed in June 2006, and two “Northeast (NE) Extension” moorings, sponsored by NOAA were deployed in June 2006. Thus for FY 2006 the total number of mooring sites occupied was 16.

For PIRATA, 8 new ATLAS moorings were deployed on 2 cruises in FY 2006. A total of 64 sea days were required to service these moorings. A 41-day cruise on the French R/V L'Atalante in May-June 2006 maintained 4 core moorings and deployed the SE Extension mooring. As has been the norm for the past several years the L’Atalante cruise was staffed entirely by technicians from IRD. A 51-day cruise on the NOAA Ship Ronald H. Brown in May-July 2006 maintained 1 core moorings and deployed the 2 NE Extension moorings. PMEL personnel spent 46 person-days and AOML personnel spent 144 person-days at sea on the Brown cruise. In addition to these scheduled cruises, the Brazilian DHN provided ship time to recover a SW Extension mooring which had gone adrift. Brazil did not provide ship time for scheduled maintenance in FY 2006. A cruise aboard the Brazilian R/V Antares is scheduled for October-December 2006 to provide maintenance for 5 core and 3 SW Extension moorings.

All PIRATA moorings measure wind speed and direction, air temperature, relative humidity, short wave radiation, precipitation, sea surface temperature and salinity, ocean temperatures at 10 depths down to 500 m and salinity at 3 depths down to 120 m. Three PIRATA sites have been proposed as flux reference sites (see 2.3 below), two of which were enhanced for flux measurements in FY 2006.

PIRATA moored time series data are available from the PIRATA web site (www.pmel.noaa.gov/pirata/) and the TAO web site (www.pmel.noaa.gov/tao/disdel/disdel.html). There are also mirror sites in France and Brazil. Collection, processing, and dissemination of shipboard CTD and ADCP data are the responsibility of France and Brazil.

Real-time data return was 75% overall for FY 2006, 3% higher than for FY 2005. Sites with the lowest data return were 0, 35W (28%), 6S, 10W (30%), 8N 38W (38%), and 0, 10W (66%). The mooring at 0, 10W was vandalized, went adrift in February 2006, and went aground on the Coast if Ghana in March. Through the collaboration of IRD, the University of Ghana and PMEL, some of the surface instrumentation was recovered and returned to PMEL, along with the delayed-mode data contained in its memory. A new mooring was deployed at this site in June 2006. The mooring at 6S, 10W stopped transmitting in September 2005. When recovered in June 2006 it was found to have been vandalized. Delayed-mode data obtained from memory increased the data return from this site to 93%. Much of the real-time data loss at 8N, 38W and 0, 35W is due to loss of subsurface measurements. These sites have not yet been recovered, but all or some of these data may be available after the moorings are recovered in November 2006. PIRATA data return remains lower than data return for TAO/TRITON of 82%. The difference between the two arrays relates to the greater susceptibility of the smaller PIRATA array to fishing vandalism and to a less frequent servicing schedule (one per year or less vs. twice per year for much of the Pacific).

Real-time PIRATA data return by variable for FY 2006 (and for comparison, FY 2005) is shown below.

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	SAL	ALL
FY 2006	72	78	73	91	67	74	87	72	75
FY 2005	78	69	74	70	78	72	76	66	72

During the May 27—July 16 2006 PIRATA Northeast Extension (PNE)/AMMA cruise of the R/V Ronald H. Brown, NOAA/AOML personnel and AMMA collaborators collected a suite of observations in support of PIRATA and AMMA. A total of 105 CTD and LADCP casts were conducted to 1500 m depth, including casts at the PIRATA sites 15ºN, 38ºW; 11.5ºN, 23ºW; 4ºN, 23ºW; 0º, 23ºW, and the future PNE site 20.5ºN, 23ºW. Seabeam bathymetric surveys were conducted at these PIRATA sites while occupying the stations. Continuous shipboard ADCP measurements were made along the track by the 75 kHz Ocean Surveyor system, including the meridional 23ºW section from 20.5ºN to 5ºS. The cruise was also used to opportunistically deploy 15 Argo floats, 21 surface drifting buoys, and 105 expendable bathythermographs in the northeast Tropical Atlantic region. All XBT temperature profiles and CTD temperature/salinity profiles were transmitted in near-real time on the Global Telecommunication System (GTS) for model calibration and validation. While XBT data is commonly transmitted on the GTS from Voluntary Observation Ships, this is the first time to our knowledge that CTD profiles have been transmitted in near-real time on the GTS for weather and climate prediction. Meteorological observations collected by AMMA collaborators on the cruise include skin SST, radiation, direct turbulent flux measurements, and atmospheric sonde and ozone sonde profiles.

The TAO Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON, PIRATA and Indian Ocean data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2006, a total of 12943 separate user requests delivered 47,354 PIRATA data files. These numbers are up 234% and 79%, respectively from the year before.

PIRATA data are distributed via the GTS to centers such as NCEP, ECMWF, and Meteo-France where they are used for operational weather, climate, and ocean forecasting and analyses. PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily averaged subsurface temperature and salinity data are also transmitted on the GTS. Daily ftp transfers are made from PMEL to the CORIOLIS operational oceanography program in France. The MERCATOR program in France makes use of the CORIOLIS data base to generate operational ocean model based data assimilation products. PIRATA data are also available on the GODAE server in Monterrey, California.

2.2 Indian Ocean

The Indian Ocean influences the dynamics of the Indian and Asian monsoons. It also remotely affects the climate over the US and North America via monsoon-ENSO interactions and via atmospheric intraseasonal oscillations which are spawned over the Indian Ocean. The Indian Ocean is much less well sampled than either of the other two tropical basins however, resulting in serious limitations in the ability to predict seasonal-to-interannual climate variability. Thus, international planning efforts assign a high priority to establishing a comprehensive *in situ* observing system in the Indian Ocean. As in the two other tropical basins, a broad scale Indian Ocean moored buoy array will form the cornerstone of systematic *in situ* ocean measurement efforts designed to improve description, understanding, and prediction of large ocean-atmosphere interactions and their influence on regional and global climate. The CLIVAR/GOOS Indian Ocean Panel has developed a design for this array available at http://www.clivar.org/organization/indian/.

All ATLAS moorings deployed in the Indian Ocean have the PIRATA suite of instrumentation, plus one additional water temperature measurement, 2 additional salinity measurements and one near surface velocity measurement. Four ATLAS moorings (at 1.5N, 0, 1.5S and 80.5E; and0, 90E) and one subsurface ADCP mooring (at 0, 80.5E) were deployed by PMEL and India's National Institute of Oceanography from the Indian R/V Sagar Kanya in October-November 2004. The 0, 80.5E ATLAS mooring was enchanced for flux refererence measurements (see 2.3 below)

All four of the surface moorings were vandalized to some degree with transmissions stopping at 1.5N, 80.5E in January 2005, at 1.5S, 80.5 E in May 2005, and at 0, 80.5E in August 2005. While transmissions did not stop at the 0, 90E mooring, no good data were received after May 2006. The ATLAS mooring design lifetime is 1-year, but ship time for maintenance of these moorings was not available until August 2006. None of the moorings along 80.5E were recovered. The 0, 90E mooring had been stripped of most sensors and was fouled with fishing line. As might be expected, the combination of vandalism, plus the lack of annual maintenance, FY 2006 real-time data return from Indian Ocean ATLAS mooring sites was low, 12%. The subsurface ADCP mooring was recovered and returned 100% data for its 22 month long deployment. New moorings were deployed at all sites, plus an additional ATLAS mooring at 1.5N, 90E, by the ORV Sagar Kanya in August-September 2006.

PMEL is working with international partners to develop new resources for expansion of the Indian Ocean moored buoy array. With invaluable assistance from Sid Thurston of NOAA's Office of Climate Observation, we have been granted 15 sea days on RV Baruna Jaya I from Indonesia's BPPT for deployment of 2 additional ATLAS moorings in November 2006. .

2.3 Flux Reference Stations

The OCEAN Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES) is built around a worldwide network of long-term, deepwater reference stations measuring many oceanographic and meteorological variables of relevance to climate and biogeochemical cycles. PMEL is a major contributor to OceanSITES in the context of the Tropical Ocean Atmosphere (TAO) mooring array in the tropical Pacific, the Pilot Research Moored Array in the Tropical Atlantic (PIRATA), and the Indian Ocean moored buoy array under development. Four equatorial Pacific moorings within the TAO Array, three PIRATA moorings, and eight moorings in the Indian Ocean have, or are scheduled to have, full air-sea heat, moisture and momentum flux measurement capability. Enhancements to the primary measurements of each array provide the functionality for all flux reference moorings to measure shortwave and longwave radiation, precipitation, sea level pressure, water temperature with higher vertical resolution, surface and subsurface salinity at 8 depths, and velocity at multiple depths. All 4 TAO moorings (along the equator at 110W, 140W, 170W, 165E), 2 of 3 PIRATA moorings (10S, 10W and 0, 23W), and 1 Indian Ocean ATLAS mooring (0, 80.5E) were enhanced for flux measurements in FY 2006.

2.4 Tropical Sea Surface Salinity

The goal of this program element is to ensure that all tropical moorings measure sea surface salinity (SSS) for improved documentation of SSS variability, ENSO forecasting, and validation of satellite salinity missions scheduled for launch in 2007 (SMOS by the Eurpoean Space Agency) and in 2009 (Aquarius by NASA). Funding in FY 2006 provided support to instrument moorings of TAO array, which is that last of the arrays in the three ocean basins needing SSS sensors. At the end of FY 2006 all PIRATA and

Indian Ocean moorings, and 33 of 55 TAO moorings were equipped to measure surface salinity. Additional instruments were procured in FY 2006 and will be used to increase the number of moorings making surface salinity measurements in FY 2007.

2.5 Engineering Development

The goal of this program element is to design and develop a next generation mooring system for use in NOAA's tropical moored buoy arrays. This effort builds on the 30 years of expertise at PMEL in moored buoy programs and takes into account requirements for improved measurement and data transmission capabilities in the future.

Funding was received in April '06 and we accomplished several steps in advancing the state of NOAA's in-situ open ocean observation systems. We are developing PICO (Platform and instrumentation for Continuous ocean Observations) mooring system which makes use of new and commercially available sensors and instrumentation and which addresses issues of improved data return rates in areas prone to vandal induced data losses. This effort is motivated by the need to develop a mooring system to replace and significantly improve upon the performance of existing ATLAS moorings used in NOAA's contribution to tropical moored buoy arrays in support of climate research and forecasting. Specifically we are developing a self deployed surface mooring technology designed with the following characteristics:

- Low cost
- Significantly safer operations
- Ship of opportunity deployable
- Rugged & self-deploy
- Pre-packaged and palletized
- Vandal resistant

A machine was built to simulate high cycles of ocean deployments for tension and bending of mooring lines and termination. The DLT (Dynamic Line Testing) machine consists of variable speed rotating spindle, that simulates bending and a ball-screw linear actuator that simulates tension. From this machine, we are starting to learn important interactions and failure mechanisms of mooring line construction and necessary bending strain relief in the upper 1-2m of the mooring.

New Seabird OEM inductive modems have been procured and tested on the bench and on PICO mooring lines. Findings of the tests include the need for a small and easy to manufacture electrode at the bottom of the inductive section of the mooring line. Planned deployment is for early 2007.

We determined the physical properties of PICO lines and built a base PICO mooring model. Mass, wet weight and diameters were obtained from manufactures specifications, backed up with actual measurements of test segments. Preliminary efforts concentrated on 3 potential problem areas in the baseline mooring design, 1) Termination, 2) Jacketed rope and 3) Weighted section. Results of this effort were captured as part of an internal 22 page engineering report.

This recent design effort on the PICO Profiler follows on the success of previous steps which validated the basic concepts: The integrated mooring and profiler self deployment scheme; subsurface telemetry from a profiler on the mooring line; wave driven mechanism to move the profiler along the mooring line. The profilers developed and used for those tests were limited in scope but clearly showed the actual profiler must be very robust and have a small virtual mass. Consequently, we focused on power requirements (to minimize batteries or power generation requirements) and on materials that would provide high strength and low weight with limited corrosion potential.

A cast titanium ‘drive pawl’ was refined and fabricated to grip the mooring line when engaged. A small neoprene rubber link was designed to attach the pawl to a unique magnetic actuator. The failure mode and lifespan of elastomer materials are being evaluated with a custom made fixture that cycles the parts in cold sea water. A link will see approximately 6 million cycles so this small element deserves a significant effort.

The magnetic actuator is imbedded in a carbon filled PEEK tube which has been machined and tested for structural properties in the PMEL pressure vessel. Mandrel wound carbon fiber tubes have been fabricated and tested for housing all electronics and sensors. A cast titanium end cap with imbedded jam cleats for holding line ties has been designed and fabricated. The body of the profiler has been made from vacuum formed UHMW Polyethylene which gives a strong shape and some buoyancy. We have purchased PVC foam for the PROFILER but it will receive significant testing to assure it will perform as specified. A draft paper on the topic of profiling float CTD sensors was carefully studied with the plan to integrate an SBE sensor into the PROFILER. The PICO concept and profiler results were presented at the technical workshop of the DBCP on October 16, 2006 in San Diego, CA.

The PICO mooring concept calls for an instrument that moves up and down the mooring line measuring and transmitting subsea data, including CTD data. For this effort two small prototype CTD sensors manufactured by Sea Bird Electronics have been purchased and integrated into an instrument. One instrument was modified to reduce the power requirements and the other was maintained as a control. The vehicle to carry the two instruments was designed and fabricated and tested at PMEL. The vehicle falls down a wire suspended from the ship, drops weights at the bottom of the wire, and then floats back smoothly to the surface where the system is recovered and the data is extracted. A total of 5 drops were made to depths up to 225m using a variety of travel velocities and intake ports. The data collected from this cruise is very encouraging and we are optimistic further processing will yield the information needed.

FLEX (Flexible and Low-powered Electronics for ocean eXperiments) electronics and software including CPU, serial and analog interface and power switching and Iridium and short-haul RF modems were designed, built and are currently being evaluated in the Laboratory. Instruments that were procured and are currently under testing include: 1) Vaisala WXT 510 which combines air temperature, relative humidity, wind, rain and barometric sensor in a single package; 2) Seabird Electronics prototype temperature, salinity, now called SBE-51 and; 3) joint PMEL-RDI current meter development and testing now called the Doppler Volume Sampler (DVS) with spec sheet available: http://www.rdinstruments.com/dvs.html. An expected field test for the FLEX electronics is scheduled for early 2007.

3. Vandalism

Vandalism continues to present a problem in all three tropical ocean basins. Data and equipment return are generally lower in regions of high tuna catch, namely the far western and eastern portions of the tropical Pacific, in the Gulf of Guinea in the Atlantic, and near 80E in the Indian Ocean. Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP. The attractive RM Young wind sensor may be replaced with a less conspicuous sonic anemometer if tests of the latter prove encouraging and funding for system upgrades become available. Evaluation of field-tested sonic anemometers is presently underway. Development of a more compact mooring (see 2.5 above) is also underway at PMEL. This mooring may possibly be less easily found by fishermen and more difficult to attach to.

4. Community Service

McPhaden, the TAO Project Director, is chairman of the Tropical Moored Buoy Implementation Panel and serves on the PIRATA Scientific Steering Committee (SSC), the OceanSITES Science Team, the CLIVAR/GOOS Indian Ocean Panel, the CLIVAR Pacific Panel, the CLIVAR Global Synthesis and Observations (GSOP) Panel, and the JCOMM Observations Coordination Group. He is an editor for the *Bulletin of the American Meteorological Society* and serves on the Executive Committee of the AGU Ocean Sciences Section. In 2006 he attended several CLIVAR panel meetings, two PIRATA SSC meetings (in Toulouse France and in Brazil), and an OceanSITES planning meeting (Honoulu).

Paul Freitag, The PMEL TAO Project Manager, represents the Tropical Moored Buoy Implementation Panel at the JCOMM Data Buoy Cooperation Panel (DBCP), and serves on the OceanSITES Data Team. He attended the DBCP meeting in October 2005

(Buenos Aires), a JCOMM Workshop on Real Time Metadata in February 2006 (Reading, UK), the first OceanSITES Data Team meeting in March 2006 (Honolulu), a NOAA/BKRT Workshop in June 2006 (Bali, Indonesia), and Oceans2006 in September 2006 (Boston).

Rick Lumpkin serves on the PIRATA Scientific Steering Committee (SSC), the CLIVAR Tropical Atlantic Climate Experiment (TACE) working group on observations, and represents the Global Drifter Program at the JCOMM Data Buoy Cooperation Panel. In 2006 he attended the PIRATA SSC meeting in Toulouse France and served as chief scientist of leg one of the Northeast Extension cruise aboard the R/V Ronald H. Brown.

Christian Meinig, the PMEL Engineering Director, made several presentations on OCO sponsored ocean observing technology including: 1) ONR/MTS Buoy Workshop in College Station, Texas March 2006, 2) Dr. Kusmayanto Kadiman. State Minister for Research and Technology of the Republic of Indonesia in July 2006 (Seattle), 3) Joint Australian Bureau of Meterology (BOM) and Indonsesia BPPT meeting September 2006; 4) Attended Ocean 2006 (Boston) and 5) Invited DBCP presentation in October 2006 (San Diego).

5. Publications and Reports

5.1 Refereed Publications

Behrenfeld, M.J., K. Worthington, R.M. Sherrell, F.P. Chavez, P. Strutton, M.J. McPhaden, and D.M. Shea, 2006: Controls on tropical Pacific ocean productivity revealed through nutrient stress diagnostics. *Nature, 442,* 1025-1028.

Bennett, A.F., B.S. Chua, H.-E. Ngodock, D.E. Harrison, and M.J. McPhaden, 2006: Generalized inversion of the Gent-Cane model of the Tropical Pacific with Tropical Atmosphere-Ocean (TAO) data. *J. Mar. Res., 64*, 1-42.

Cheng, W., M.J. McPhaden, D. Zhang, and E.J. Metzger, 2006: Recent changes in the Pacific subtropical cells inferred from an eddy resolving ocean circulation model. *J. Phys. Oceanogr.,* in press.

Cronin, M.F., C. Fairall, and M.J. McPhaden, 2006: An assessment of buoy derived and numerical weather prediction surface heat fluxes in the tropical Pacific. *J. Geophys. Res., 111,* C06038, doi:10.1029/2005JC003324.

Delcroix. T., S. Cravatte, and M.J. McPhaden, 2006: Decadal variations and trends in tropical Pacific sea surface salinity since 1970. *J. Geophys. Res.,* submitted.

Feely, R.A., T. Takahashi, R. Wanninkhof, M.J. McPhaden, C.E. Cosca, S.C. Sutherland

and M.-E. Carr, 2006: Decadal Variability of the Air-Sea CO_2 Fluxes in the Equatorial Pacific Ocean. *J. Geophys. Res., 111.*, C08S90, doi:101029/2005JC003129.

Foltz, G.R. and M.J. McPhaden, 2006: Unusually warm sea surface temperatures in the tropical North Atlantic during 2005. *Geophys. Res. Lett.,* 33, L19703, doi:10.1029/2006GL027394.

Foltz, G.R. and M.J. McPhaden, 2006: The role of oceanic heat advection in the evolution of tropical North and South Atlantic SST anomalies. *J. Climate*, in press.

Maes, C., K. Ando, T. Delcroix, W.S. Kessler, M.J. McPhaden, and D. Roemmich, 2006: Observed correlation of surface salinity, temperature and barrier layer at the eastern edge of the western Pacific warm pool. *Geophys. Res. Lett., 33,* L06601, doi:10.1029/2005GL024772.

McPhaden, M.J., X. Zhang, H.H. Hendon, and M.C. Wheeler, 2006: Large Scale Dynamics and MJO Forcing of ENSO Variability. *Geophys. Res. Lett., 33*(16), L16702, doi:10.1029/2006GL026786.

McPhaden, M. J., S. E. Zebiak, and M. H. Glantz, 2006: ENSO as an integrating concept in Earth Science. *Science*, in press.

Morris, V., P. Clemente-Colon, N. R. Nalli, E. Joseph, R. A. Armstrong, Y. Detres, M. D. Goldberg, P. J. Minnett and R. Lumpkin, 2006: AEROSE Science Team Conducts Ongoing Investigations of Downwind Transport from Saharan and Sub-Saharan Africa in the Tropical Atlantic. *EOS*, in press.

Schein, K.A. et al, 2006: The state of the climate 2005. *Bull. Am. Meteorol. Soc., 87,* S1-S102.

Zhang, D., and M.J. McPhaden, 2006: Decadal variability of the shallow Pacific meridional overturning circulation: relation to tropical sea surface temperatures in observations and climate change models. *Ocean Modelling*, in press.

Zhang, X. and M.J. McPhaden, 2006: Wind stress variations and interannual sea surface temperature anomalies in the eastern equatorial Pacific. *J. Climate, 19,* 226-241.

5.2 Other Reports and Publications:

Freitag, H. P., M. J. McPhaden, M. F. Cronin,C. L. Sabine, D. C. McClurg, and P. D. McLain, 2006: PMEL contributions to the OceanSITES program. Proc. Oceans2006 MTS/IEEE Conference, 18-21 September 2006, Boston, MA.

McPhaden, M.J., 2006: El Niño and Ocean Observations: A Personal History. In: *Physical Oceanography*, Developments Since 1950. M. Jochum and R. Murtugudde (Eds.), Springer, New York, p. 79-99.